British Heart Journal, 1975, 37, 242–248.

Measurement of conduction times with catheter electrodes during pacing from different ventricular sites

Agustin Castellanos, Jr., Abdul S. Agha, Benjamin Befeler, and Robert J. Myerburg
From the Division of Cardiology, Department of Medicine, University of Miami School of Medicine, and the Medical Service, Veterans Administration Hospital, Miami, Florida, U.S.A.

Filtered bipolar catheter electrodes, 1 mm apart, were used to pace and record from the high right atrium, right ventricular apex, right ventricular outflow tract, right ventricular inflow tract, middle cardiac vein, great cardiac vein, and endocardium of the left ventricular septal surface. Right ventricular apex to middle cardiac vein and the middle cardiac vein to right ventricular apex conduction intervals gave a rough estimate of anteroposterior and posteroanterior 'transseptal plus free left ventricular wall' conduction times, respectively. On the other hand, the right ventricular apex to left ventricular septal surface and left ventricular septal surface to right ventricular apex intervals represented pure 'transseptal' conduction times, since both sets of electrodes were in contact with the respective septal surface. During stimulation of the intermediately-located right ventricular inflow tract propagation to the right ventricular apex and right ventricular outflow tract was longer than between these two sites. Moreover, conduction was almost as delayed to the right ventricular apex and right ventricular outflow tract as it was to the left ventricular septal surface. These findings were attributed to the peculiar electrophysiological behaviour of the right ventricular inflow tract muscle. Pacing from different segments of the great cardiac vein produced QRS morphologies and arrival of excitation patterns consistent with the relation between the anatomical location of this structure and the recording electrodes. However, from this study no inferences could be drawn regarding the conduction velocity or specific conduction pathways used by the stimulus in its journey from stimulating to recording areas.

There are few studies dealing with the sequence of arrival of excitation at several recording sites during ventricular stimulation using the newer techniques of catheter recordings (Castellanos and Castillo, 1972; Castellanos *et al.*, 1973a). Therefore, justification existed to present information obtained from three patients, which can be of help in understanding the mechanisms of intraventricular conduction in the human heart.

Subjects and methods

The technique for obtaining filtered (40–400 Hz) and 'local' ventricular electrograms, 1 mm apart, used in our department has been discussed elsewhere (Castellanos and Castillo, 1972; Castellanos *et al.*, 1973a). Only pertinent information will be presented in the corresponding case descriptions which include data from three symptomatic patients referred for electrophysiological studies. The latter were performed after the procedure had been explained to the patients and next of kin, and consent had been obtained.

Received 6 June 1974.

Case reports

Case 1

In this patient (data from which have been presented elsewhere, Castellanos *et al.*, 1973b) catheters were introduced for stimulation and recording from the high right atrium (HRA), His bundle area (HBE), right ventricular apex (RVA), and middle cardiac vein (MCV). The latter explored, or paced, the posteroinferior surface of the ventricles (Fig. 1).

Beats elicited from the right ventricular apex showed prolonged duration and superior and leftward deviation of the electrical axis with a predominantly negative deflection in lead V1 (Fig. 2, left). Those arising in the posteroinferior ventricular wall were also wide. Though they had superior and slightly leftward orientation of the electrical axis, a major positive deflection was recorded in lead V1 (Fig. 2, right).

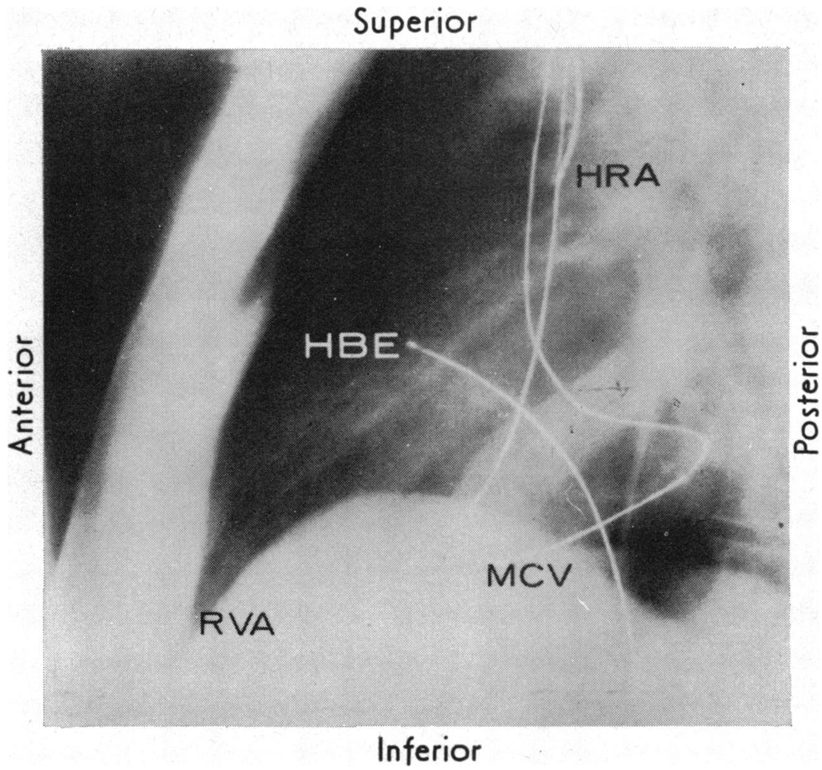

FIG. 1 (*Case 1*). *Lateral* x-ray *view showing the position of the pacing and recording catheter electrodes. HRA = high right atrium; HBE = His bundle electrogram; RVA = right ventricular apex; MCV = middle cardiac vein.*

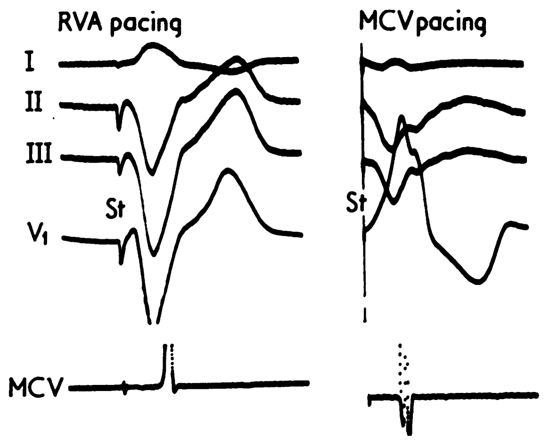

FIG. 2 (*Case 1*). *QRS morphologies and arrival of excitation patterns produced by pacing from the right ventricular apex (left) and middle cardiac vein (right). St = pacemaker stimulus artefact. In this and all figures paper speed was 100 mm/s.*

These morphologies are in keeping with previously made assumptions (Castellanos and Lemberg, 1969). The St (RVA)-MCV (Fig. 2, left) and the St (MCV)-RVA (Fig. 2, right) intervals had a duration of 115 ms and 95 ms, respectively. These values gave a rough measurement of anteroposterior and posteroanterior conduction times.

Case 2

Additional information regarding this patient has been presented elsewhere (Castellanos *et al.*, 1973a). Several catheters were introduced pervenously (Fig. 3) to pace and record from the His bundle area at the right ventricular inflow tract (RVIT), right ventricular outflow tract (RVOT), and great cardiac vein (GCV). Another catheter was also introduced retrogradely into the left ventricle to stimulate or record from the middle left septal surface (LVE in Fig. 3).

The electrical axis of the pacemaker-induced beats was superiorly-oriented (as in Fig. 2, left) when the right ventricular apex was stimulated, and vertically-oriented when the right ventricular outflow tract was paced. On both occasions, however, V1 showed a predominantly

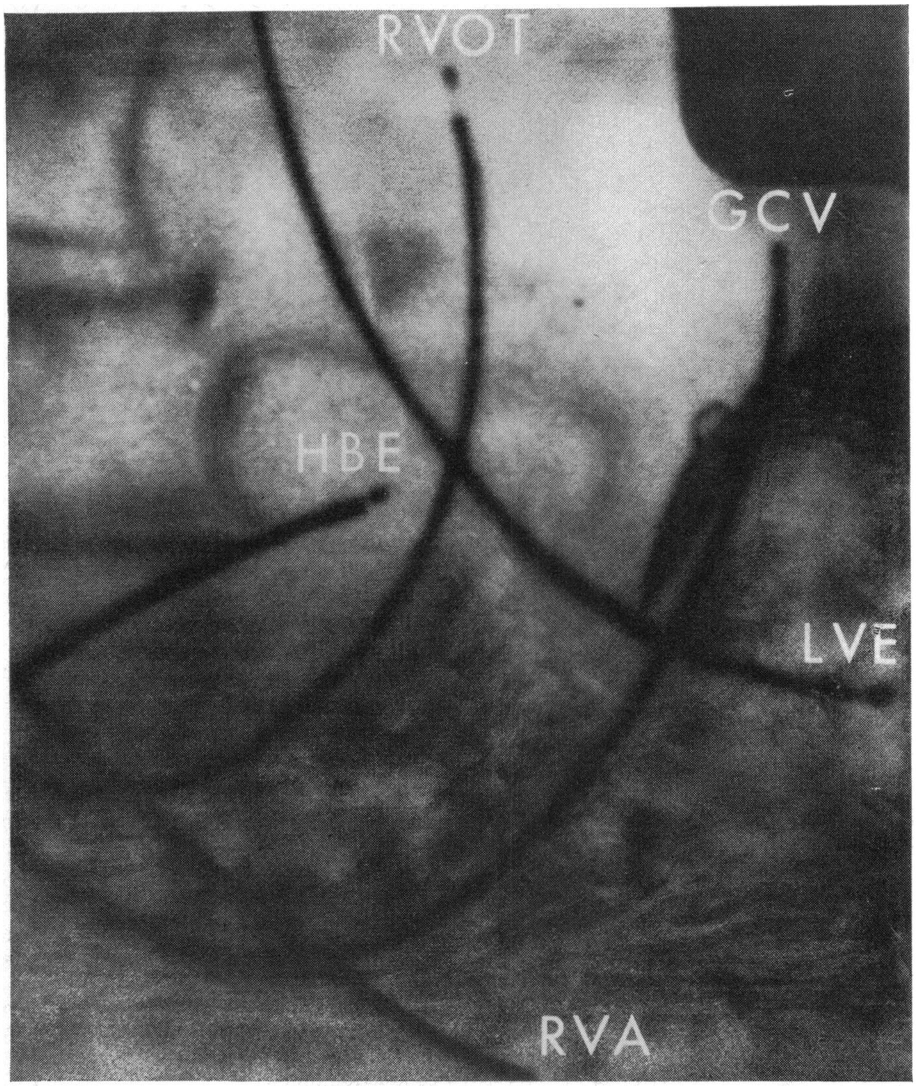

FIG. 3 (*Case 2*). *Right anterior oblique view showing the position of the pacing and recording catheter electrodes. GCV = great cardiac vein; LVE = left ventricular (septal) endocardium; RVOT = right ventricular outflow tract.*

negative deflection, indicating that the electrical forces were moving away from the paced right ventricle. The St (RVA)-RVOT and the St (RVOT)-RVA conduction times measured 60 and 65 ms, respectively (Fig. 4, left and middle frames).

The right-to-left transseptal conduction time given by the St (RVA)-LVE interval had a duration of 85 ms.

The electrical axis of beats induced by left ventricular septal surface pacing was oriented towards the right. V1 showed a predominantly positive deflection (Fig. 4, right panel). The left-to-right transseptal conduction time, given by the St (LVE)-RVA interval, measured 65 ms.

Interesting results were observed when the right ventricular inflow tract (RVIT) was stimulated from the His bundle area (Fig. 5). The wide (165 ms) QRS complexes had an electrical axis of around +50° as previously reported by Castellanos and Castillo in 1972. Lead V1 showed a predominantly negative deflection preceded by a wide, slurred, r wave with a duration of 85 ms. In other words, though smaller, the r wave was wider than the deeper S wave.

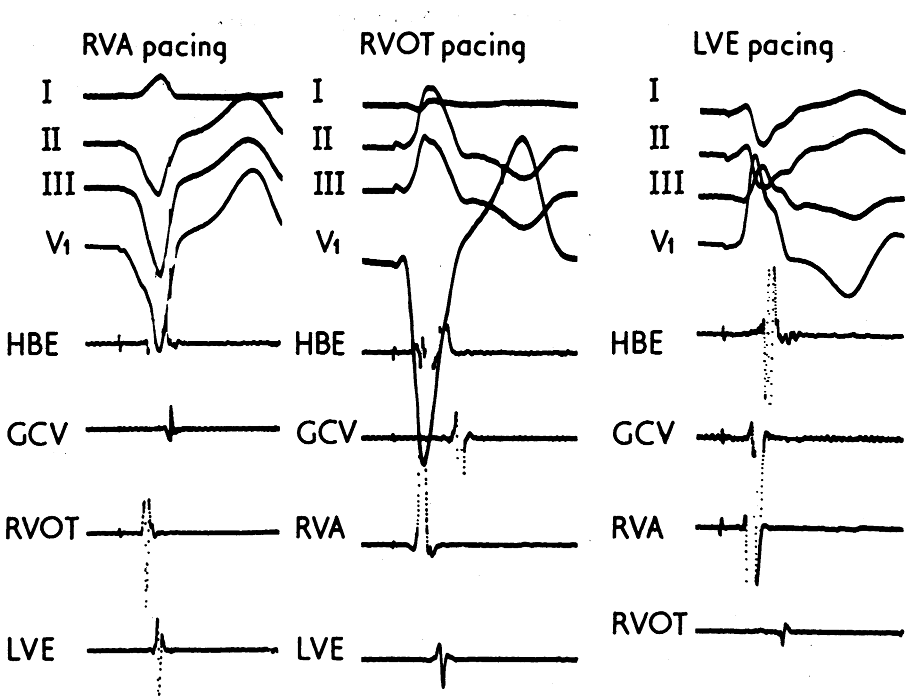

FIG. 4 (*Case 2*). *QRS morphologies and arrival of excitation patterns produced by stimulation of right ventricular apex (left), right ventricular outflow tract (middle), and left ventricular septal surface (right).*

Moreover, the St (RVIT)-RVA, St (RVIT)-RVOT, and St (RVIT)-LVE intervals measured 100, 105, and 110 ms, respectively. This indicated that the impulse was as delayed in reaching other regions of the *right* ventricle as in arriving at the *left* ventricular endocardium.

Case 3

In this patient with repetitive ventricular tachyarrhythmias catheters were introduced to record from the right ventricular apex, right ventricular outflow tract, His bundle area, and middle cardiac vein to try to locate the site of origin of the ectopic beats. An additional catheter was introduced gradually into the great cardiac vein. From its distal end, adjacent to the coronary sinus, the resulting QRS complex showed inferior and rightwards deviation of the electrical axis with a predominantly positive deflection in V1 (position 1 in Fig. 6). The impulse was considerably delayed in arriving at both the right ventricular apex and right ventricular outflow tract (150 ms and 140 ms, respectively).

Advancement of the catheter into the great cardiac vein (position 2 in Fig. 6) produced a QRS complex with an inferior and leftward axis (around +60°) and a predominantly positive deflection in lead V1. The St-RVA and St-RVOT measured 105 ms and 70 ms, respectively. Pushing the catheter as far as possible into the great cardiac vein (position 3 in Fig. 6) resulted in an axis similar to that obtained from position 2. In contrast, V1 showed an rS pattern in which the duration of the slurred r wave was 95 ms. The St-RVA and St-RVOT intervals had a duration of 85 and 45 ms, respectively. Note that as the catheter was advanced into the great cardiac vein it became closer to the one in the right ventricular outflow tract as can be determined by the progressive decrease of the St-RVOT interval.

Finally, when the catheter was withdrawn and introduced into the middle cardiac vein (last panel in Fig. 6) the corresponding, pacer-induced, QRS complex had a similar morphology to the one shown in Fig. 2, right. The St (MCV)-RVA and St (MCV)-RVOT intervals measured 120 ms and 155 ms, respectively.

Discussion

Right ventricular conduction times during right ventricular pacing

In the cases studied the superior and inferior orientation of the electrical axis depended on the spatial, inferior, or superior site of stimulation as judged best by the anteroposterior or lateral *x*-ray views. This was first suggested by Barker, McLeod, and Alexander in 1930, who stated, 'that this ten-

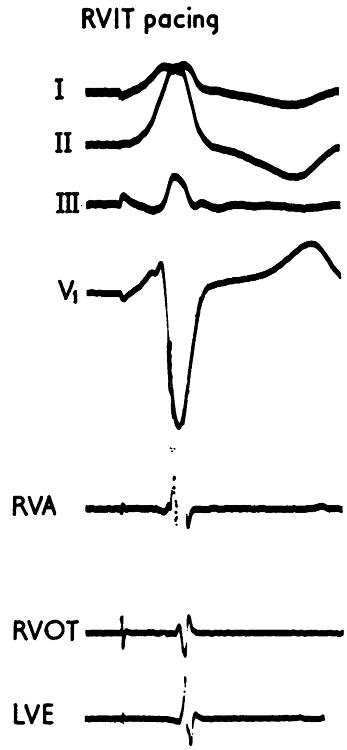

FIG. 5 (*Case 2*). *QRS morphology and arrival of excitation patterns during stimulation of the ordinary (non-specialized) muscle at the right ventricular inflow tract (RVIT) with a catheter located over the so-called (radiological) His bundle area.*

dency of the electrical deflections to become more negative (in leads II and III) as the lower portion of the ventricles was approached (excited) is more striking and orderly if reference is made to the *cephalic* (superior) and *caudal* (inferior) aspects of the heart as it lies on the body.'

Hence, the right ventricular apex to right ventricular outflow tract and right ventricular outflow tract to right ventricular apex gave a rough measurement of right ventricular inferosuperior and superoinferior conduction times. The values obtained from the first patient are in keeping with the previously reported normal ranges (Castellanos *et al.*, 1973a).

It was, therefore, unexpected to observe in Case 2 that stimulation from an area (right ventricular inflow tract) located between the 'cephalic' (right ventricular outflow tract) and 'caudal' (right ventricular apex) resulted in conduction times which were at least 45 ms longer to the right ventricular apex and right ventricular outflow tract than the conduction times between the latter two sites (Fig. 5).

The complexities of the ventricular electrogram recorded by the His bundle electrogram lead at the right ventricular inflow tract have been discussed previously (Castellanos and Castillo, 1972). It was found that this electrogram could not be used to determine the moment of arrival of excitation at the recording electrodes. Moreover, the findings in Case 2 indicate that propagation from the paced (septal) right ventricular inflow tract area occurred very slowly through the ordinary right ventricular muscle. This assumption was corroborated by the great width (85 ms) and slurring of the r wave in V1 (Fig. 5).

In fact, Sodi-Pallares and Calder (1956) noted that after experimentally-induced right bundle-branch block there was no delay in activation in certain septal areas of the right ventricular inflow tract. These authors suggested that the areas where this occurred behaved, electrophysiologically, as if they were left ventricular, rather than right ventricular, muscle.

In their studies of Wolff-Parkinson-White syndrome, Moore, Spear, and Boineau (1972) noted that experimentally-induced pre-excitation of certain right ventricular septal areas was 'electrically silent' (not recorded) in the surface electrocardiogram, presumably (we believe) because propagation was extremely slow.

More studies are necessary to determine the exact cause of the bizarre electrophysiological behaviour of the ventricular muscle at the right ventricular inflow tract.

The electrical axis was deviated superiorly when the *inferior* parts of the ventricles were stimulated, regardless as to whether pacing was performed anteriorly from the endocardium of the right ventricular apex (Fig. 2, left, and Fig. 6, right) or posteriorly from a vein close to the epicardium of the *left* ventricle. However, the QRS complex was predominantly negative in the former cases and mainly positive in the latter instances, because of the different directions (in the anteroposterior axis of the heart) in which the corresponding impulse propagated.

Differences between the moment in which the stimulation was applied to the inferiorly-located right ventricular apex and its arrival at the (also inferiorly located) middle cardiac vein can be considered as a measurement of anteroposterior intraventricular conduction time whereas the St(MCV)-RVA gave a rough measurement of posteroanterior conduction time.

Although no inferences can be drawn regarding the pathways followed by the electrical impulse in

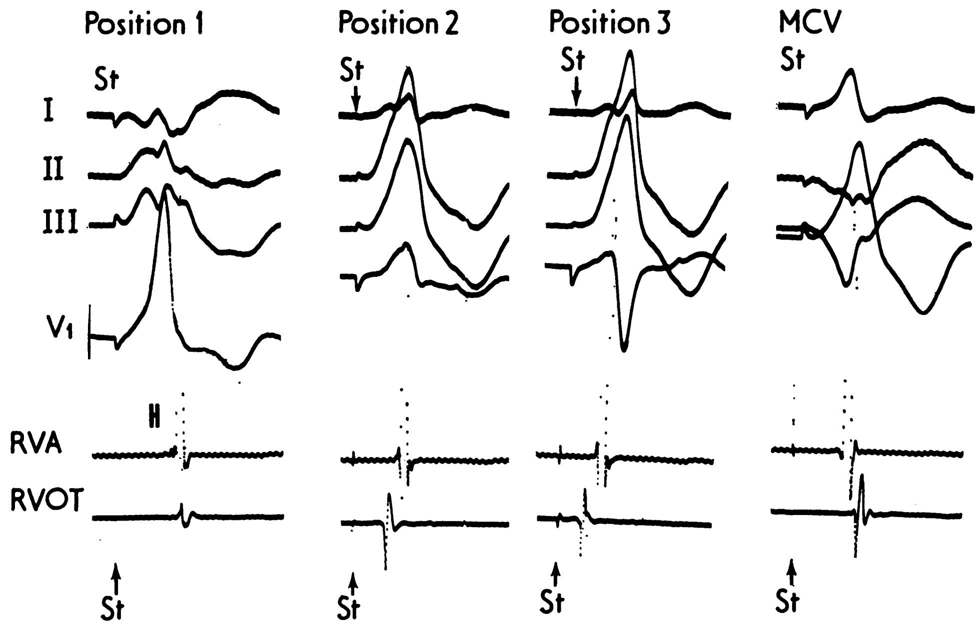

FIG. 6 (*Case 3*). *QRS morphologies and arrival of excitation during stimulation of the middle cardiac vein (right) and from different segments of the great cardiac vein. Position 1 is closest and position 3 farthest from the coronary sinus.*

its journey from one site to another it is possible that some parts of the left ventricular wall had to be traversed since the middle cardiac vein is located at the epicardial surface. Therefore these measurements might have included transseptal as well as free wall conduction times.

Transseptal conduction time in the human heart

Katz and Pick (1963) used this term in reference to the time required by the impulse to propagate from a left ventricular site (not necessarily located within or close to the septum) to a given right ventricular site, and vice versa. Studies performed by other authors measuring the so-called forward or retrograde conduction times were similar, in that they measured conduction through the septum as well as through certain parts of the free ventricular wall (Linenthal, Zoll, and Bell, 1963; Gerbaux and Lenegre, 1964).

In contrast, when two catheters are in contact with the right and left septal surfaces, a more reliable measure of 'pure' transseptal conduction time can be obtained. When this was done as far as technically possible with catheter recordings (Case 2) the values obviously did not reflect the 'minimal' transseptal conduction time. A 'linear' measurement of conduction velocity across the septum requires that pacing and recording catheters be at the same horizontal level, one in front of the other. Obviously this was not the case in our studies in which the right ventricular catheters were at a different level from the left ventricular one (Fig. 3).

It should also be stressed that the previously mentioned paradoxical behaviour of right ventricular inflow tract stimulation was also manifested by the fact that the conduction times from this site to other *right* ventricular recording areas were more or less the same as to the anatomical *left* septal surface (Fig. 4 and 5).

QRS morphologies and arrival of excitation times during pacing from different segments of great cardiac vein

The morphology of the beats excited from the great cardiac vein depended on the position of the catheter within this structure. From the segment that was closer to the coronary sinus the electrical axis of QRS complexes showed an inferior and rightwards orientation. The right ventricular apex and right ventricular outflow tract were activated with more or less the same degree of delay (Fig. 6, position 1).

The location of the great cardiac vein within the left-sided atrioventricular sulcus is such that as the catheter was advanced through this vein it moved from a superoposterolateral to a superoanterolateral position. In consequence, it became closer and closer to the superiorly and anteriorly-located right ventricular outflow tract catheter as manifested by the decreasing St-RVOT intervals from position 1 to position 3 in Fig. 6.

Importance of bipolar ventricular electrograms obtained with catheter electrodes

The majority of studies performed with newer sophisticated techniques of catheter recordings (those using filters, short interelectrode distances, multiple simultaneous leads at fast paper speeds, and high fidelity instruments) have dealt mainly with His bundle electrograms as they relate to atrioventricular conduction.

We have extended their application to the measurement of arrival of excitation at 'selected' ventricular sites. Whether this study is superior to those previously performed with non-filtered unipolar electrograms remains to be proven, possibly by the more accurate epicardial recording techniques, similar to the ones used by Kupersmith, Krongrad, and Waldo (1973).

References

Barker, P. S., McLeod, A. G., and Alexander, J. (1930). The excitatory process observed in the exposed human heart. *American Heart Journal*, **5**, 720.

Castellanos, A., Jr., Agha, A. S., Befeler, B., Castillo, C. A., and Berkovits, B. V. (1973a). A study of arrival of excitation at selected ventricular sites during human bundle branch block using close bipolar catheter electrodes. *Chest*, **63**, 208.

Castellanos, A., Jr., and Castillo, C. A. (1972). His bundle recordings in right bundle-branch block coexisting with iatrogenic right ventricular pre-excitation. *British Heart Journal*, **34**, 153.

Castellanos, A., Jr., Castillo, C. A., Agha, A. S., Myerburg. R. J., and Tessler, M. S. (1973b). Mechanisms of ventricular tachycardia. In *Cardiac Arrhythmias*, pp. 235–243. Ed. by L. S. Dreifus and W. Likoff. Grune and Stratton, New York.

Castellanos, A., Jr., and Lemberg, L. (1969). *Electrophysiology of Pacing and Cardioversion*, pp. 171–177. Appleton-Century-Crofts, New York.

Gerbaux, A., and Lenegre, J. (1964). Observations sur les rhythmes à double commande (sinusale et par électrostimulation) constatés après implantation d'un stimulateur interne pour maladie d'Adams-Stokes. *Archives des Maladies du Coeur et des Vaisseaux*, **57**, 286.

Katz, A. N., and Pick, A. (1963). The transseptal conduction time in the human heart. An evaluation of fusion beats in ventricular parasystole. *Circulation*, **27**, 1061.

Kupersmith, J., Krongrad, E., and Waldo, A. L. (1973). Conduction intervals and conduction velocity in the human cardiac conduction system. Studies during open-heart surgery. *Circulation*, **47**, 776.

Linenthal, A. J., Zoll, P. M., and Bell, A. B. (1963). Ventricular fusion beats and myocardial conduction time in man; their significance for anomalous atrioventricular excitation. *Circulation*, **28**, 758.

Moore, E. N., Spear, J. F., and Boineau, J. P. (1972). Electrophysiological studies in pre-excitation in the dog using an electronically simulated atrioventricular bypass pathway. *Circulation Research*, **31**, 174.

Sodi-Pallares, D., and Calder, R. M. (1956). *The New Bases of Electrocardiography*. C. V. Mosby, St. Louis.

Requests for reprints to Dr. Agustin Castellanos, University of Miami School of Medicine, P.O. Box 520875 Biscayne Annex, Mimai, Florida, 33152, U.S.A.